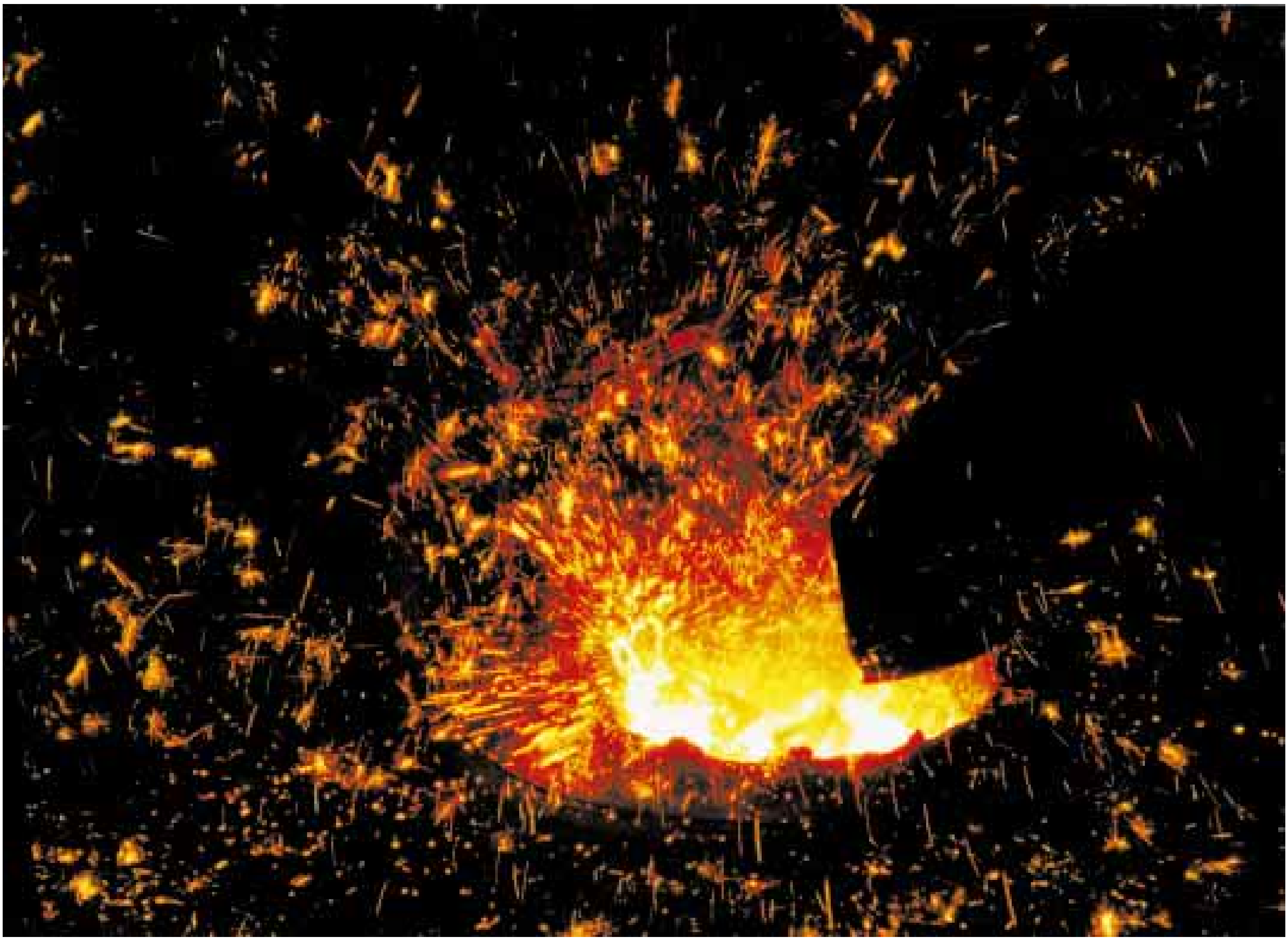
GOOD PRACTICE GUIDE 63

Metal distribution and handling in iron foundries



ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

GOOD PRACTICE GUIDE 63

METAL DISTRIBUTION AND HANDLING IN IRON FOUNDRIES

This guide is No. 63 in the Good Practice Guide series and is intended to help operators of iron foundries who wish to make energy savings. The Guide covers methods of transport, holding, superheating and metal treatments. The Guide also deals with the efficient use of energy through correct specification and the improved use of equipment. It is estimated that applying the principles of good energy management to metal handling and distribution will help the UK iron foundry industry to save energy worth up to £2 million each year.

Prepared for the Energy Efficiency Best Practice Programme

ETSU
Harwell
Didcot
Oxfordshire
OX11 0QJ

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Energy Efficiency Enquiries Bureau
ETSU
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Didcot
Oxfordshire
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FOREWORD

This Guide is part of a series produced by the Government under the Energy Efficiency Best Practice Programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

— *Energy Consumption Guides:* (blue) energy consumption data to enable users to establish their relative energy efficiency performance;

— *Good Practice Guides:* (red) and *Case Studies:* (mustard) independent information on proven energy-saving measures and techniques and what they are achieving;

— *New Practice projects:* (light green) independent monitoring of new energy efficiency measures which do not yet enjoy a wide market;

— *Future Practice R&D support:* (purple) help to develop tomorrow's energy efficiency good practice measures.

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ENGLAND

London
Govt Office for London
6th Floor
Riverwalk House
157-161 Millbank
London
SW1P 4RR
Tel 020 7217 3435

East Midlands
The Sustainable Development Team
Govt Office for the East Midlands
The Belgrave Centre
Stanley Place
Talbot Street
Nottingham
NG1 5GG
Tel 0115 971 2476

North East
Sustainability and Environment Team
Govt Office for the North East
Wellbar House
Gallowgate
Newcastle-upon-Tyne
NE1 4TD
Tel 0191 202 3614

North West
Environment Team
Govt Office for the North West
Cunard Building
Pier Head
Water Street
Liverpool
L3 1QB
Tel 0151 224 6401

South East
Sustainable Development Team
Govt Office for the South East
Bridge House
1 Walnut Tree Close
Guildford
Surrey
GU1 4GA
Tel 01483 882532

East
Sustainable Development Awareness Team
Govt Office for the East of England
Heron House
49-53 Goldington Road
Bedford
MK40 3LL
Tel 01234 796194

South West
Environment and Energy Management Team
Govt Office for the South West
The Pithay
Bristol
Avon
BS1 2PB
Tel 0117 900 1700

West Midlands
Regional Sustainability Team
77 Paradise Circus
Queensway
Birmingham
B1 2DT
Tel 0121 212 5300

Yorkshire and the Humber
Sustainable Development Unit
Govt Office for Yorks and the Humber
PO Box 213
City House
New Station Street
Leeds
LS1 4US
Tel 0113 283 6376

NORTHERN IRELAND
IRTU Scientific Services
17 Antrim Road
Lisburn
Co Antrim
BT28 3AL
Tel 028 9262 3000

SCOTLAND
Energy Efficiency Office
Enterprise and Lifelong Learning Dept
2nd Floor
Meridian Court
5 Cadogan Street
Glasgow
G2 6AT
Tel 0141 242 5835

WALES
Business and Environment Branch
National Assembly for Wales
Cathays Park
Cardiff
CF10 3NQ
Tel 029 2082 5172

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MANAGEMENT SUMMARY

This Guide focuses on the efficient handling and distribution of metal in iron foundries. It covers methods of transport (such as metal conveying with ladles or launders), holding, superheating and metal treatments. The Guide also deals with the efficient use of energy through correct specification and the improved use of equipment, in addition to the minimisation of energy dissipation through proper design, insulation, preheating, etc.

The most recent Energy Consumption Guide for Ferrous Foundries (ECG 48), published in January 2000, indicated that energy worth £105 million was consumed by 200 iron foundries in producing 1.4 Mt of castings during 1998. In many cases, excess melting energy is used to compensate for inadequacies in subsequent molten metal handling and distribution systems. While some losses are inevitable, considerable energy savings can be achieved by paying proper attention to processes and handling systems, together with good operational practice and equipment maintenance.

It is believed that applying the principles of good energy management to metal handling and distribution will help the UK iron foundry industry to save energy worth up to £2 million each year. The advice will also lead to lower incidence of casting defects, thus improving the yield of saleable castings.

The energy saving measures detailed in this Guide range from no- or low-cost good management activities and best operating practices to programmes that may require significant investment in essential plant over a longer period. However, with many investment activities, careful planning of equipment specification and location can result in relatively short payback periods.

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1. FACTORS INFLUENCING ENERGY EFFICIENCY

1.1 Introduction

UK iron foundries use in excess of £100M of energy annually in producing approximately 1.4 million tonnes of castings. Approximately two thirds of this energy is consumed in metal melting and holding operations. While a finite quantity of energy is essential to melt and superheat the metal to the required temperature for casting, all other energy inputs and losses are within the control of the foundry.

In many cases, excess energy is used in melting and holding to compensate for inadequacies in the downstream molten metal handling and distribution systems. Conservative estimates suggest that this could be as much as 10% of the total energy consumed by a foundry.

While some losses are inevitable, significant energy savings can be achieved by paying proper attention to processes and handling systems, instituting good operational practices, and following effective equipment maintenance methods. The advice provided in this Good Practice Guide will assist many foundries to redress this situation. It is estimated that realistic improvements to the distribution/handling of metal would save 10 – 20% of related energy use, valued at £1 – 2 million/year to the UK foundry industry.

1.2 Key Action Areas

The design of the molten metal distribution system is of paramount importance. Irrespective of the casting size or the production method, the requirement is to pour clean molten metal of the correct composition and temperature, at the optimum rate. In most foundries, careful examination of the molten metal distribution system will reveal opportunities to make energy and labour savings, and to reduce the quantity of wasted metal and scrap castings. The key action areas to be addressed are summarised below in order of priority.

1.2.1 *Optimum Performance of Primary Melting Systems*

Optimum performance of primary melting systems based on cupola, electric or fuel-fired furnaces can be only achieved by operating under constant conditions, with the accurate scheduling of the molten metal a vital pre-requisite. A major contribution is the capacity of the metal distribution system to move the available molten iron immediately from the melting furnace. In order to even-out any disparity between molten metal supply and demand, it may prove beneficial to use a holding furnace with a superheating capability, although the high operating costs of this equipment must be taken into account when calculating efficiencies.

1.2.2 *Control of Metal Temperature*

Rapid melting and superheating rates

The fast response of modern high-powered induction furnaces allows rapid melting and superheating rates to be achieved. However, the associated energy savings can only be realised if the molten metal handling systems are efficient.

Lower tapping temperatures

Many foundries employ tapping temperatures and/or superheating rates from prime melting and holding furnaces that are higher than necessary. This is in order to compensate for excessive energy losses and the consequent temperature drop during molten metal distribution. Melting practices, intermediate treatments and handling systems should all be designed to provide the correct temperatures at the desired pouring temperature.

Pouring temperatures

Achieving the correct pouring temperature is critical to the production of high quality iron castings. Low pouring temperatures result in mis-run castings and lap defects, while metal poured at too high a temperature promotes shrinkage cavities and inaccurate castings, resulting in reduced metal yield. A poor surface finish is often caused by incorrect pouring temperatures.

1.2.3 *Effective Launder/Ladle Practice*

Ladle lining, drying and pre-heating

Ladle lining, drying and pre-heating methods have a considerable influence on temperature losses during transfer and pouring, and poor ladle handling, preparation and maintenance can lead to casting defects. Ladle lining materials, the configuration of the ladles, and the provision of proper drying and pre-heating facilities are important parameters.

Launder/ladle covers

Radiated heat losses are reduced when launders and ladles are fitted with insulated covers.

1.2.4 *Intermediate Metal Handling Operations*

Metal processing

It is often necessary to treat molten iron after tapping from the melting furnaces in order to modify either its composition or metallurgical characteristics. Significant temperature losses are inevitable in any such intermediate operation and it may be necessary to use a holding/superheating furnace to recover metal temperature before distribution.

Ladle transfer operations

Action should be taken to reduce any unnecessary transfer operations in order to minimise metal temperature losses during distribution.

1.2.5 *Control of Metal Pouring*

Pouring Methods

Moulds can be presented for pouring either in static groups or, where sequential pouring is desirable, on continuous/indexing conveyor systems. Selecting the appropriate pouring method is a critical consideration.

Automatic Pouring Systems

Automatic pouring machines are now available for most high production iron foundry applications. Such systems can reduce labour requirements and remove operators from a potentially hazardous environment, while eliminating extensive pouring zones and simplifying molten metal transfer systems. The energy consumption of the "melting plant" is reduced because the processes of dumping and re-melting unwanted molten metal are eliminated. Automatic pouring machines provide slag-free metal at the optimum pouring temperature, with only minor compositional variations.

Avoiding pour down

Many foundries "pour down" excessive quantities of molten iron because it is either too cold to pour into moulds, the effects of treatment have faded, or the moulds are not available for pouring. Pour down can be avoided through good planning and scheduling, which improves the yield of good castings and results in significant energy and cost savings.

1.2.6 *Handling System Design*

In general, temperature losses rise as the transportation distance between the melting/holding furnace and the pouring station is increased. Delays caused by ladle transfer operations also result in further heat losses. Although it is frequently only a secondary consideration, the need to optimise foundry layout for efficient molten metal handling and distribution is vital.

1.2.7 *Metal Handling and Casting Yield*

Both energy savings and consequent reductions in foundry costs achieved by improving the overall yield of good castings from the metal charged can be calculated. The ultimate aim is to maximise the saleable tonnage of castings from the quantity of metal charged into the prime melting furnaces. Efficient metal handling and distribution is a vital factor in reducing metal wastage through spillage and pour down. For further information see Good Practice Guide 17, *Achieving high yields in iron foundries,* available through the Environment and Energy Helpline on 0800 585794.

2. LADLE PREPARATION AND OPERATION

2.1 Overview

Many of the scrap problems experienced in iron foundries can be traced back to poor ladle practice and inadequate drying and pre-heating prior to use. Choosing the correct ladle refractory, and reducing heat losses through radiation and conduction by fitting insulated ladle covers will significantly improve energy utilisation. Careful planning is also necessary to reduce the number of ladle-to-ladle transfers that occur during metal distribution. The section concludes with some examples of casting defects resulting from poor ladle practice.

2.2 Ladle Linings

Foundry ladles are available in a wide range of sizes, with capacities varying from a few kilograms to many tonnes. Fig 1 shows a range of iron foundry ladle configurations, comprising refractory lined bucket shape or cylindrical shells.

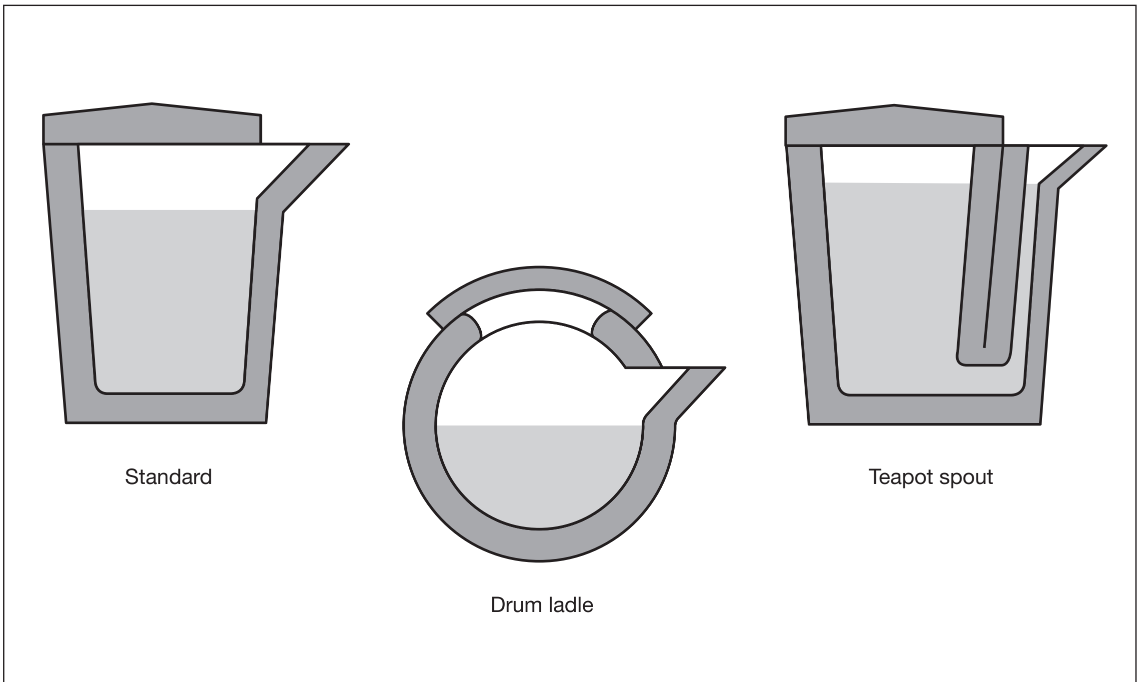

Fig 1 Typical ladle configurations

Traditionally, all but the largest iron foundry ladles have been lined with gannister, naturally bonded sand, firebrick, or a combination of these materials. When these materials are of good quality and used correctly, they are suitable for many applications and yet have a low initial cost.

Recently, there has been increased interest in more durable and more refractory lining materials, as well as those that provide better insulation against both conducted and radiated heat losses. Refractory materials based on alumina are now available in plastic and castable form. These provide highly refractory and mechanically strong linings, but are expensive and need skilled installation to achieve the best results. Special formers are needed if castable materials, including those requiring vibro-compaction, are used.

Pre-formed ladle linings and sectional refractory board materials have also been developed. The latter have found considerable use in steel casting but, as yet, are not widely used in iron foundries.

Case Study 1
Good Practice Case Study 379 *Ladle linings and feeder sleeves in ferrous foundries*

In this case study, insulated lining boards replaced cement linings, as shown in Fig 2. The new linings are disposable and, thus, do not require maintenance. Because they are made of a material with excellent insulating qualities, ladle shell temperatures are reduced, thus improving the working environment on the pouring floor. The linings are also lighter and do not require pre-heating, further contributing to energy savings and greater productivity.

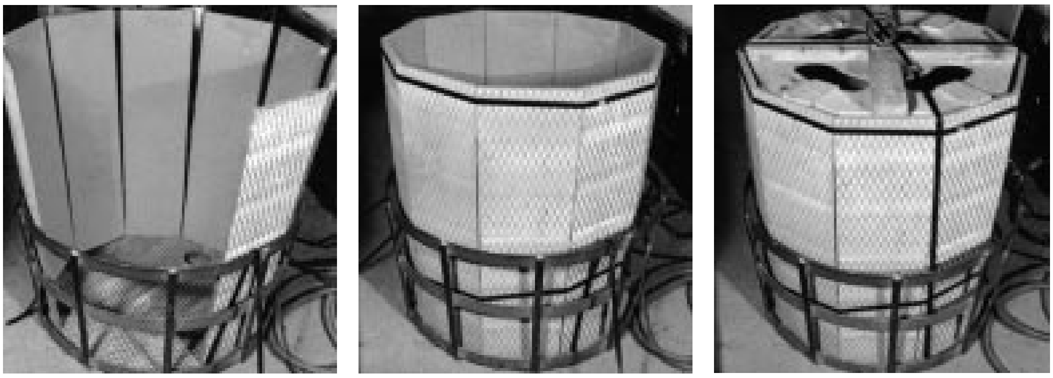

Fig 2 Insulated lining boards (courtesy of Foseco International Ltd)

Although the linings are designed for single use, multiple taps are often achieved. Frequent changes of linings, lower tapping temperatures and smoother pouring contribute to reduced inclusions and defects in the castings. The ease with which the disposable liners can be changed also reduces the possibility of employee injury.

Based upon a rate of 20 tonnes/day melting, using the insulated board system provided a daily energy saving of 1,555 kWh, i.e. 77 kWh per tonne of metal poured (inclusive of drying and pre-heating costs). In addition, there was a reduction in the power supplied to the furnaces, resulting from the 30°C lower tapping temperature permitted by the better insulating properties of the board linings. The savings of approximately 6 kWh per tonne of metal poured, or 120 kWh per day, are not included in the energy savings given above.

Further developments in ladle lining materials, such as loose fill exothermically cured refractories, are anticipated in the near future.

For smaller ladles, one-piece pre-forms may be used in place of the insulating boards. In this case, the pre-form is placed on a levelled bed of coarse silica sand (typically 20 AFS grade) and back-filled using the same material.

2.3 Heat Losses from Ladles

Heat losses from ladles are partly related to the ratio of the exposed molten metal surface to its volume. Although drum ladles may be considered more efficient in their ability to retain heat, they actually perform no better than bucket ladles with well fitted lids. When full, the metal level in a drum ladle is only just above the centreline, so the surface to volume ratio is high.

The greatest heat losses from ladles occur when they are either filled for the first time after pre-heating, or when they are only used intermittently. With continuous use, ladle temperature and heat losses will stabilise at a predictable value.

Fig 4 shows typical measured cooling rates for molten metal held in standard foundry ladles, with and without covers (see Good Practice Guide 17 *Achieving high yield in iron foundries*).

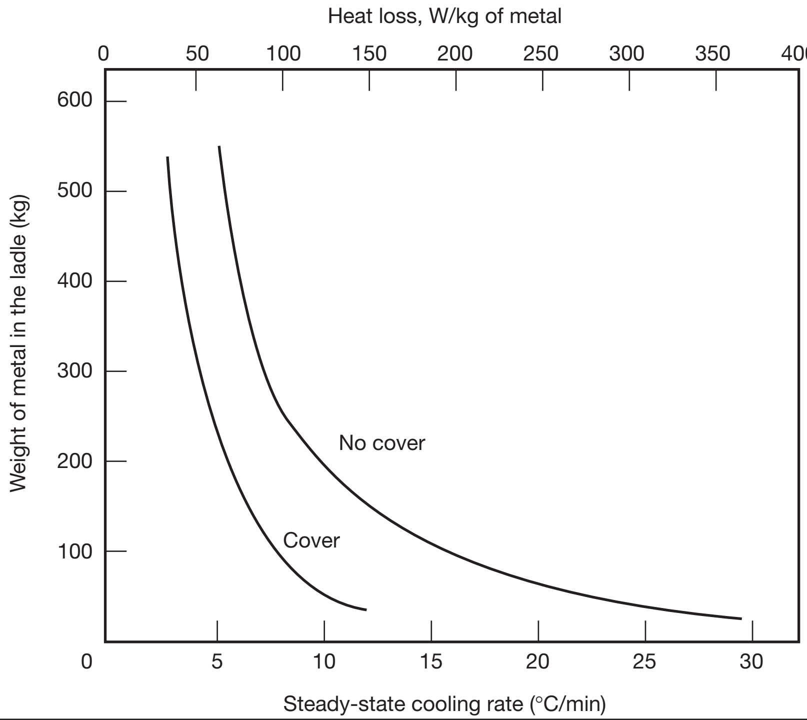

Fig 4 Metal cooling rates in ladles

Taking the example of a 100-kilogram capacity ladle, the effect of applying an appropriate cover is to reduce the steady-state cooling rate from approximately 15 to 7°C/minute. In addition, tests have shown that, while heat losses from larger capacity ladles are considerably lower, they can be effectively halved through the use of a well fitting cover.

Using an insulated ladle lining reduces the heat loss from the shell. Typically, losses are reduced from 10 to 5 kW/m^2 and result in shell temperatures being reduced by as much as 100°C. An indication of the power loss from a 1m high ladle is shown in Fig 5.

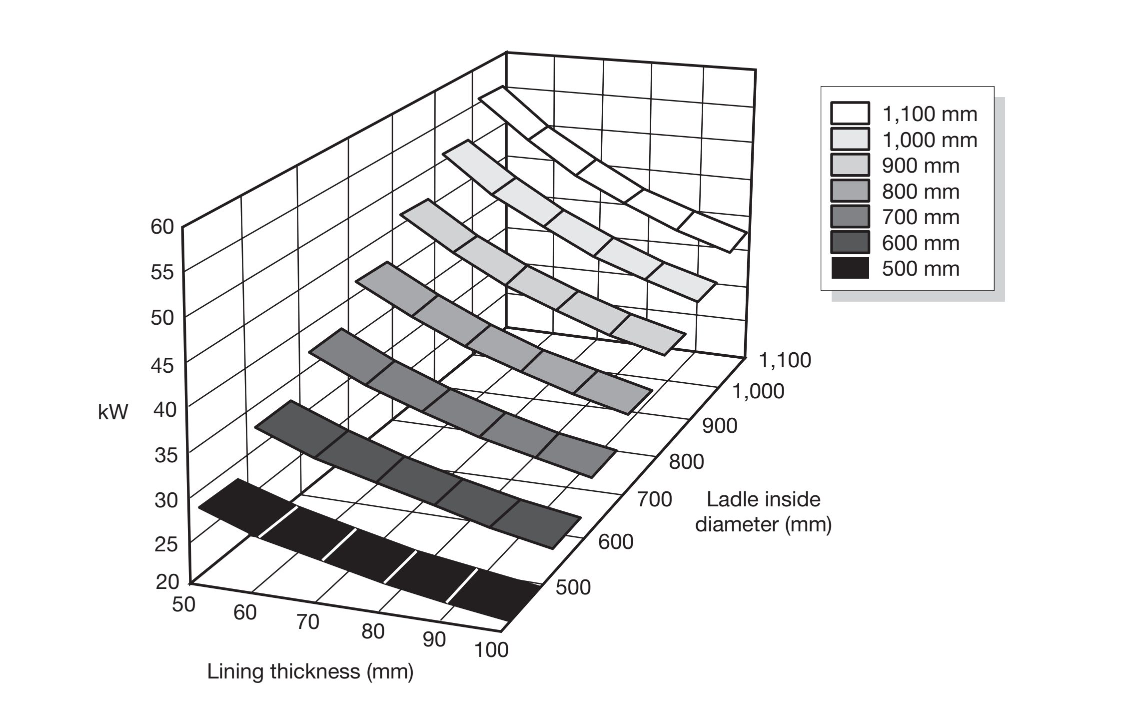

Fig 5 Energy losses in a 1m high ladle (courtesy of Lafarge Refractories)

2.4 Ladle Covers

Wherever practicable, all ladles in use should be equipped with well-fitted refractory-lined covers. Various studies have indicated that as much as 50% of the heat lost from the metal held in casting ladles is attributable to radiation from the molten metal surface. This loss can be significantly reduced by the use of a cover, as is shown in Table 1.

Table 1 Reduction of heat losses using ladle covers

Ladle	Temperature drop °C/min
250 kg (open top)	13.0
250 kg (steel cover)	10.0
250 kg (insulated cover)	8.5

The application of an insulating layer, such as silica sand, on the metal surface is not recommended. This is due to the potential for carry-over of the material during pouring, if it has not been completely removed during the deslagging operation. On no account should slag coagulant be employed as an insulating medium due to the formation of a highly fluid slag on holding, which cannot subsequently be removed.

The use of inert materials in large ladles, such as those used in large jobbing foundries, may be worth considering. Although lids cannot easily be fitted, these ladles need to be kept full for a considerable time before pouring.

The aspect ratio (i.e. ratio of surface area to volume) decreases as the ladle size increases; thus temperature losses from larger ladles are relatively small, as indicated in Table 2.

Table 2 the effect of aspect ratio on ladle heat losses

Open top ladle (in kgs)	Temperature drop °C/min
250	13
1,000	5
3,000	3
10,000	2

Ladle covers should be lined with a refractory material that has good mechanical properties and resistance to spalling. Lightweight castable refractory may be used, and alumino-silicate fibre blanket also possesses good insulating properties and has a low thermal mass. Like a ladle lining, the ladle cover lining will perform better if well vented and thoroughly dried before use.

2.5 Ladle Drying and Pre-heating

For both financial and practical reasons, the use of well designed, efficient and safe ladle heating systems is considered essential.

A good ladle heater is designed to operate over a wide range of flame conditions and temperatures. It will incorporate a refractory-lined cover, which should fit the ladle properly, thus minimising heat losses. The capacity of the heater should be sufficient to raise the lining surface temperatures in excess of 1,000°C. Most modern ladle heaters suit the majority of ladle sizes currently in use.

Table 3 shows the typical savings that can now be obtained by using a ladle heater with cover in a 500-kg capacity ladle. When compared with an open-ended gas pipe, the combined gas burner/baffle provided energy savings of 2.5 therms/hour and produced a hotter ladle lining.

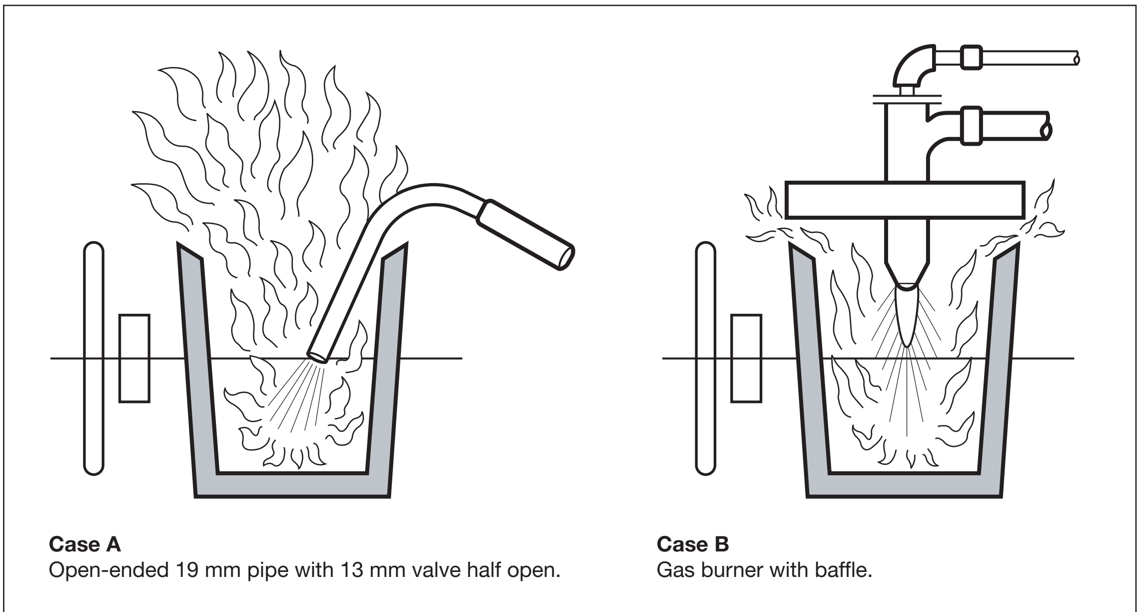

Fig 6 Energy savings with pre-heating

Table 3 Savings obtained using a ladle heater with cover in a 500 kg capacity ladle

Case A	Case B	Saving
420 MJ/h	160 MJ/h	260 MJ/h
4 th/h	1.5 th/h	2.5 th/h
120 kWh/h	45 kWh/h	75 kWh/h

The ready availability of natural gas makes it the normal fuel for ladle drying and pre-heating. Although radiant electric dryers have been developed, they have not proved to be cost-effective, due to the lower cost of gas when compared with electricity (1998 fuel costs: natural gas 0.8p/kWh and electricity 4.9p/kWh). Natural gas is easily controlled, provides adequate flame temperatures for pre-heating, and does not contaminate the ladle linings with either products of combustion or residual fuel.

A substantial amount of energy is wasted by the industry as a result of inefficient ladle drying/pre-heating practices.

Action should be taken to:

- use only effective burners - if possible, use oxy-fuel burners;
- apply heat for the minimum period possible to achieve a lining temperature of 1,000°C;
- switch off burners when not required;
- for efficient heat transfer, utilise a ladle cover or, alternatively, invert the ladle over the burner with the flame firing vertically.

Inefficient pre-heating operation can waste as much as 4 therms/hour for each unit.

On no account should gas burners be employed to heat the local foundry area in which they are located.

2.6 Casting Defects Caused by Poor Ladle Practice

Defective castings result in a high scrap rate and reduced yield. Therefore, avoiding casting defects is essential for cost effective foundry operation. However, some defects may be apparent on the unfettled casting and these are often only discovered during subsequent costly machining operations. The common defects that occur due to poor ladle maintenance, rather than to bad molten metal handling techniques, may be divided into two categories:

- Slag and dross inclusion defects;
- Hydrogen pinholing.

Hydrogen pinholing is avoided by correct ladle drying and pre-heating. It is often caused by pouring metal from ladles in which the lining refractories have not been properly dried. Damp furnace launders can also cause this problem.

It is important to use good quality refractories capable of withstanding the metal temperatures involved. It is equally important that adhering slag should be removed from the ladle lining during use and between refills. When the ladle has a teapot spout, molten slag and any residual metal should always be removed by back tilting, in order to avoid contaminating the spout riser.

Checklist

Casting quality and energy efficiency are improved by:

- Choosing the correct ladle refractory/insulation.
- Providing and using of suitable ladle drying and pre-heating facilities.
- Drying adequately to eliminate the presence of hydrogen pinholing.
- Using insulated ladle covers to reduce heat lost by radiation.
- Avoiding the use of sand/coagulant as a cover to reduce temperature losses during holding and transportation periods.

3. METAL HANDLING AND PROCESSING

3.1 General Requirements

Iron castings range in weight from a few grammes to more than 100 tonnes, and are generally made in degradable moulds. Irrespective of the size of the mould and the production method, the common requirement is for clean molten metal of the correct composition and temperature, poured into the mould at a rate appropriate for the gating system and the production of a sound casting. Fig 7 shows the various routes by which molten metal can be transferred from the prime melting furnace into the mould. The selection, design and operation of the molten metal distribution system are very important and are outlined in general principle in this section.

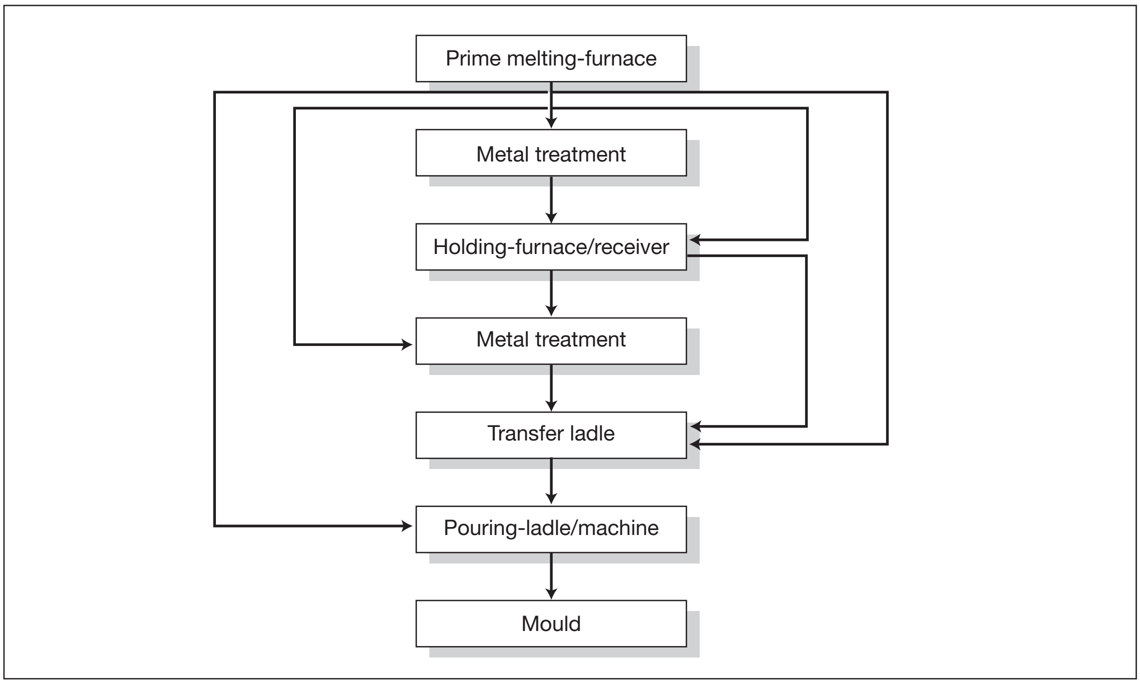

Fig 7 Alternative metal transfer routes

3.2 Melting Plant

Cupolas and coreless electric induction furnaces are used to melt most of the metal required in iron foundries. A few foundries use fuel-fired rotary furnaces, while a smaller number retain electric arc melting.

3.2.1 *Cupola Melting*

As large cupolas are almost always continuously tapped, a holding vessel is needed to receive the molten iron for subsequent distribution around the foundry. The holding vessel may be unheated or fuel-fired to maintain metal temperature. Channel-type and, occasionally, coreless induction furnaces are used for holding.

The proper installation and preparation of siphon box and launder refractories is a pre-requisite for good molten metal handling from cupolas. It is also important to appreciate the quantity of heat lost from molten metal in tapping boxes and launder systems. This will enable steps to be taken to minimise losses and to relate the size of systems to the metal flow rate. Fig 8 shows typical heat losses for launder channels of differing cross section, with and without insulating covers.

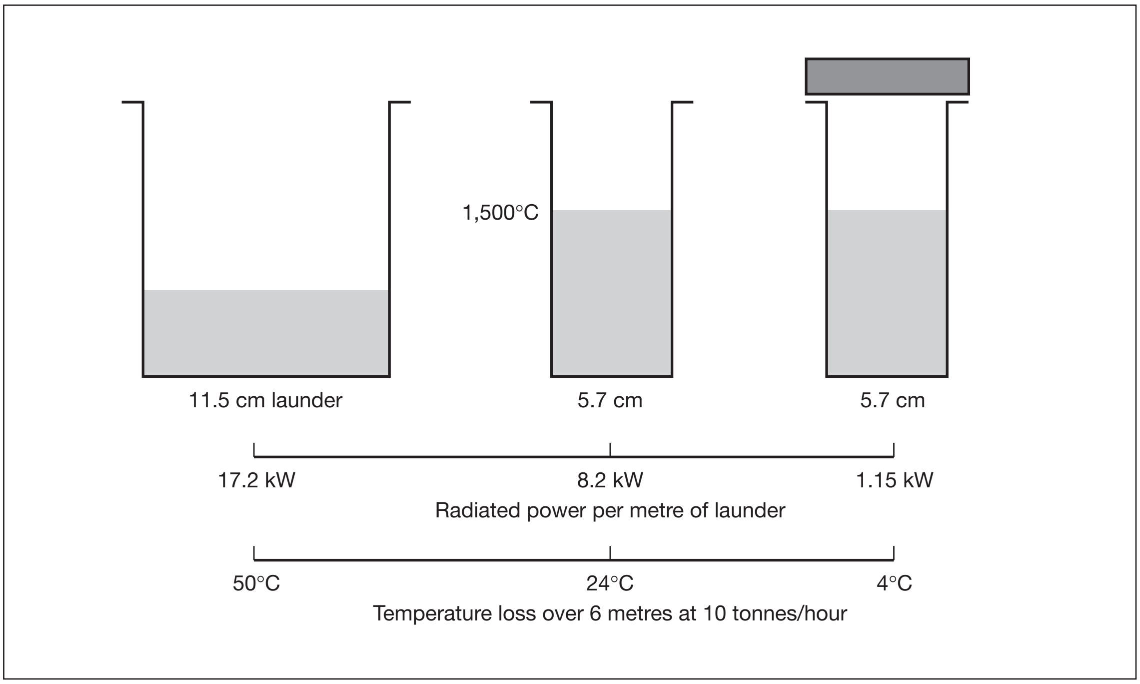

Fig 8 Heat losses from launders

Launders must be properly sized and covered in order to reduce radiation losses, where practicable. The inside of the steel launder channel is generally lined with insulating grade firebrick tiles, followed by the application of a hot face refractory. The refractory material must be of good quality and thoroughly dried and pre-heated before use.

Pre-formed launder linings in convenient lengths are now available and provide a safe, long life alternative to "green" refractory linings. Drying and pre-heating are less critical provided that the sections are bedded in a suitable material and carefully joined. Pre-formed launder covers, in similar refractory materials, are effective in reducing radiated heat loss. These liners and covers are recommended for high output, multi-shift and long campaign cupola operations.

In smaller foundries using cupola melting, metal may be tapped directly from the furnace into a ladle. The ladle may be used for metal transfer and pouring or metal may be dispensed into smaller pouring ladles at the moulding line. As the energy efficiency of these methods depends on the tapping frequency and molten metal requirement, it is particularly sensitive to foundry operations and scheduling. In many cases, coke consumption is high because of the increased coke charges required to maintain satisfactory cupola operation and metal temperatures.

Further information can be found in Good Practice Guide 58, *Cupola melting of cast iron in iron foundries*.

3.2.2 *Coreless Induction Melting*

Most of the electric melting plant used in iron foundries is based on the use of coreless induction furnaces. Only a small number of foundries use channel or electric arc furnaces.

The coreless induction furnace is an easily operated and versatile melting tool and units are available with a capacity ranging from a few kilograms to in excess of 30 tonnes. Solid state rectifier/inverter units are now the standard means of powering induction furnaces. High power density, medium frequency units (200 - 600 Hz) now dominate and all new installations are based on this type of equipment.

With furnaces operating at frequencies in excess of 250 Hz, it is possible to melt down a solid, cold charge in an empty furnace relatively quickly, making the production of various grades and alloys by the same plant much more practicable. Fig 9 shows a typical modern induction furnace system.

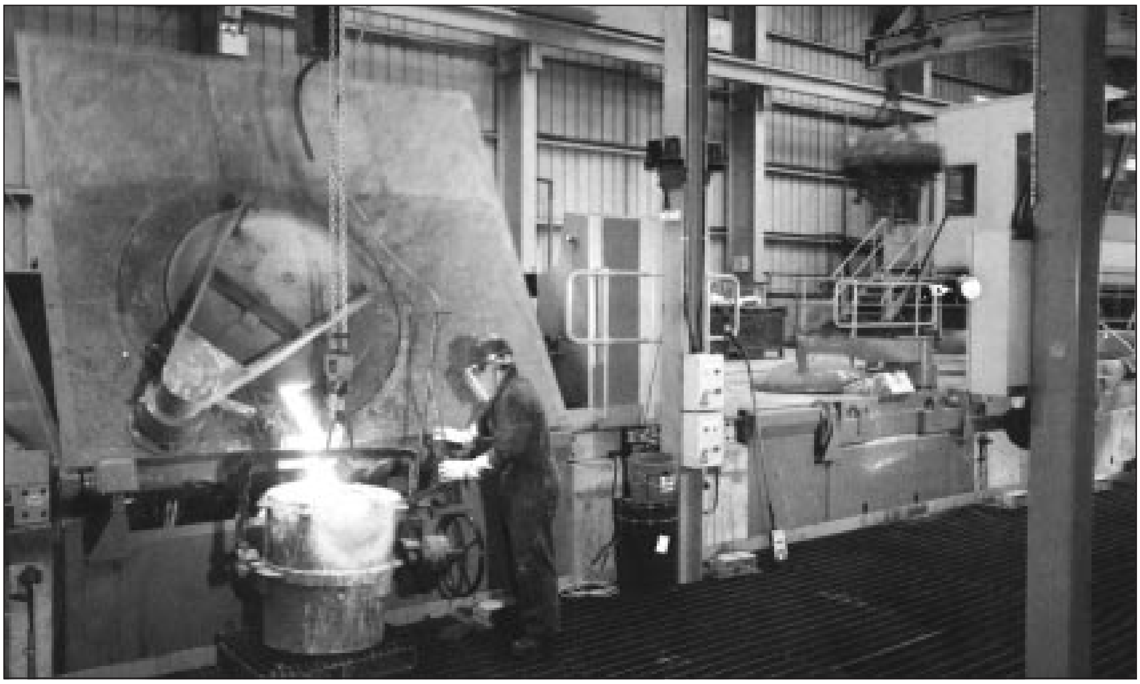

Fig 9 Metal transfer from a coreless melting unit

In medium frequency furnaces, superheating is rapid and the temperature of the melt is easily raised. Care must be taken to avoid attaining too high a temperature. In most iron foundry operations, molten metal can be distributed fairly quickly. This avoids problems, such as the reduced levels of nucleation associated with long holding times, and makes inoculation and post-furnace treatment easier.

Further information regarding melting in coreless induction furnaces can be found in Good Practice Guide 50 *Efficient melting of cast iron in coreless induction furnaces*.

3.3 Molten Metal Treatment

It is often necessary to carry out some pre-treatment of the molten iron after it has been tapped from the prime melting furnace, prior to either its storage in a holding furnace or before its distribution to the foundry. These treatments are sometimes carried out in an intermediate vessel. In other cases, materials are added to transfer or pouring ladles, either before or during filling.

The principal pre-treatments used in iron foundries are:

- Recarburisation;
- Desulphurisation;
- Alloy addition;
- Inoculation;
- Nodularisation.

3.3.1 *Recarburisation*

In general, it is preferable to attain the correct metal composition in the prime-melting furnace through suitable charge material selection and control. There are few difficulties involved in achieving the correct carbon/silicon values in modern induction furnaces, as carburiser and silicon-bearing materials can be added to the melt directly.

When cupola melting ductile iron, it may not be possible to achieve the required "as tapped" carbon content economically, making external recarburisation necessary. This practice should be avoided unless the molten iron can be agitated to improve recovery and there are facilities for re-heating the metal after treatment. The dissolution of carbon in molten iron is endothermic and the absorption of 0.1% carbon (by weight) results in a temperature loss of about 7°C.

3.3.2 *Desulphurisation*

Sulphur is a major rogue element that can cause chilled (brittle) edges and surface blows in iron castings. A variety of methods are used for desulphurising cupola melted iron, including:

- shaking ladle systems - molten metal is agitated in a vessel mounted on an oscillating frame to mix in the desulphurising agent; and
- porous plug vessels - agitation is achieved by injecting a gas bubble stream into the molten metal.

Mechanical mixing and injection systems have been used, but are not widely accepted.

The metal to be treated must be slag-free and sufficiently superheated to compensate for temperature losses during processing, as these can be as high as 60°C. Furthermore, the reaction/treatment vessels must be cleaned and pre-heated before use.

3.3.3 *Metallic Additions to Molten Iron*

During the production of both grey and ductile castings, small additions of metallic elements may be made to the ladle receiving molten metal from the prime melting or holding furnaces. The most commonly added elements are chromium, copper and tin.

The pre-weighed alloying elements must be added to hot metal via a clean, slag-free metal surface to ensure their complete dissolution.

While the addition of "cold" material to molten iron will have a cooling effect, the amount added is generally small and has only minimal influence on metal temperature.

3.3.4 *Inoculation*

The formation of eutectic carbide or white iron structures is commonly referred to as "chill". Certain materials counteract this effect when added in small amounts to molten iron just before pouring. The process of addition is known as "inoculation".

The effects of inoculation fade rapidly with time. Therefore, the inoculant must be added to the metal as late as possible before pouring into the mould. In the production of both grey and ductile iron, the inoculant is usually added directly to the metal stream entering the ladle. As with metallic additions, the small quantity of additive ensures that temperature losses are minimal.

3.3.5 *Nodularisation*

The production of ductile iron castings requires a molten base iron of the correct chemical composition with a low sulphur content. Cupola melted iron invariably requires desulphurisation (Section 3.3.2).

Several methods for adding magnesium to molten iron have been developed and most are based on the use of magnesium-bearing ferrosilicon alloys in granular, lump or wire form.

When planning handling systems for treated ductile iron, it should be noted that the fade rate due to magnesium oxidation limits the period of time that the treated metal can be kept before pouring. In small to medium sized operations, where demand is fairly constant, simple pour-on methods of nodularisation are favoured. For high volume foundries, or those producing large castings with a heavy regular metal requirement, the plunger or converter methods will generally prove more economical. These methods also allow desulphurisation to be effected during the treatment.

Whichever treatment method is chosen, it is essential to ensure that correct pouring temperatures are maintained and that the metal is slag/dross-free in handling prior to pouring.

When an open ladle is used for treatment, moulds can be generally poured directly from the ladle. Otherwise, the metal must be tapped from the prime melting furnace into the treatment vessel and dispensed into smaller ladles for pouring. With converters, metal may have to be transferred from the melters to fill the vessel, thus involving two transfer operations and likely greater temperature losses. It is essential that tapping temperatures are adequate, ladles and treatment vessels are properly pre-heated and, wherever possible, ladles are fitted with insulated covers during transport.

Many iron foundries now use automatic pouring units to control dispensing molten metal into the mould. These are generally of the pressure pouring channel induction furnace type, in which the furnace bath is sealed and nitrogen can be used as the pressurising medium to reduce the rate of magnesium oxide formation. This system allows for long holding periods with negligible fade. Filling and pouring spouts are prone to blockage, so care is needed to keep these clear at all times during dispensing operations.

3.4 Hot Metal Receivers and Holding Furnaces

In the modern mechanised or automated foundry, it is essential to provide a readily available supply of molten metal, backed by the capacity to cope with constant variations in demand. In addition, melting capacity must be used efficiently even when demand is low or temporary plant stoppages occur. Often, these requirements are achieved by the provision of adequate holding capacity for molten metal.

Depending on the requirements of a particular plant, holding furnaces principally provide a reservoir of molten metal to cater for variations in plant demand, which enables efficient use of the prime melting systems. Holding furnaces maintain molten metal at the correct temperature for distribution and, on occasion, enable superheating of molten metal following intermediate treatment. Their application smoothes out compositional variations in the metal received from the primary melting systems and permits compositional adjustments to be made.

The use of holding furnaces allows extended melting shifts to be operated in order to take advantage of cheaper off-peak electricity tariffs - typically, 45% of the normal tariff.

Holding furnaces take the form of either unheated or heated metal receivers.

- Unheated receivers are generally unsatisfactory. Heat losses are high and satisfactory metal temperatures cannot be maintained except by excessive superheating in the prime melters. Therefore, unheated units are not recommended for use in modern foundries.

- Heated receivers and holding furnaces can be categorised as fuel-fired (using oil or gas) or electrically heated. While fuel-fired hot metal receivers are relatively cheap to install, maintain and operate, they generally have a low fuel-efficiency. Super-heating is not possible with this type of unit and this factor, accompanied by increasing fuel costs, has led to a decline in their use. With fuel-fired receivers, oxidation of metal in the bath and consequent slag build-up can occur during long holding periods.

Channel or coreless induction-holding furnaces are used in most applications and especially when a superheating capability is required.

In terms of energy efficiency, the thermal performance of different furnaces of comparable size and electrical rating is very similar. The holding power requirement (i.e. the energy loss from a channel furnace) depends on the capacity of the unit and, particularly, the rating of the inductor fitted.

Substantial costs are incurred when holding metal outside normal production periods. Case Study 2 demonstrates that, in terms of energy consumption alone, holding and superheating molten iron is expensive. The need for large holding furnaces must be considered carefully and their advantages carefully compared to their costs.

In a "typical" foundry there are 5,000 non-productive hours per year. Therefore, nearly 50 per cent of the energy is consumed in holding molten metal when the foundry is not working. Furthermore, as Case Study 2 shows, less than 20% of the energy is used "usefully", i.e. to raise the metal temperature.

Case Study 2

A channel furnace of 30 tonne useful capacity fitted with an inductor rated at 500 kW exhibits heat losses equivalent to about 250 kW. Assuming a throughput of molten iron and an average superheating rate, the approximate specific electrical energy consumption can be calculated as:

Assume:	i	Average holding power = 250 kW
	ii	Melting rate of primary melter = 10 tonnes/hour
	iii	16 hours per day operation (2 shifts)
	iv	Operates 47 x 5 day weeks per year
	v	Average superheating requirement = 50°C
	vi	Energy consumption for superheating = 23 kWh per 100°C

Annual consumption for holding = 365 x 250 x 24 = 2,190,000 kWh

Annual metal production = 47 x 5 x 16 x 10 = 37,600 tonnes

$\therefore$ Energy required for superheating $= 37{,}600 \times 23 \times \frac{50}{100} = 432{,}400$ kWh

Total energy consumption per year = 2,190,000 + 432,400 = 2,622,400 kWh

$\therefore$ Specific energy consumption $= \frac{2{,}622{,}400}{37{,}600} = 69.7$ kWh per tonne

At 4.5 p/kWh = 2,622,400 x 0.045 = £118k per year
= 69.7 x 0.045 = £3.14 per tonne

of which "useful" energy to raise temperature $= \frac{432{,}400}{2{,}622{,}400} = 16.5\%$

Good Practice Guide Number 68, *Electric holding of hot metal in iron foundries*, provides a detailed look at the operation of electric holding furnaces.

3.5 Casting Defects Arising from Poor Metal Handling

Most defects that arise from poor molten metal handling are attributable to either dirt or dross entering the mould (inclusions), or cold metal being poured.

3.5.1 *Inclusions*

Dirt or dross inclusions arising from slags carried over into the ladle from prime melting or holding furnaces can generally be avoided by:

- following good melting practice;
- using high quality launder and ladle refractories;
- cleaning ladles and metal.

While metal composition, treatment practice and running system design are of paramount importance in avoiding dross defects, good ladle maintenance and handling can help to alleviate the problem.

Using teapot spout ladles or slag dams across the pouring lip helps to prevent surface dross entering the mould. These devices should be used with caution, as any slag and dross retained in the ladle and spout will contaminate the next fill. Teapot spout ladles are not recommended for pouring ductile iron because of the danger of dross contaminating the spout riser.

Other inclusion defects occasionally arise from either the excessive use of slag coagulants, or the fact that the material is not immediately removed from the metal surface following its application. This leads to the formation of a very fluid slag, which is extremely difficult to remove.

3.5.2 *Temperature Related Effects*

Monitoring and controlling metal temperatures and not pouring cold metal into the mould are an intrinsic part of good melting practice. Sub-surface blowholes, which are associated with the segregation of manganese sulphide inclusions, are often linked with low metal pouring temperatures and bad metal handling. These blowholes, which are a common reason for grey iron castings to be rejected, occur beneath the casting skin, generally on the upper surface as cast in the mould. The defects may be revealed by shotblasting, but are more commonly detected after the first machining cut.

To eliminate the incidence of such defects:

- maintain an adequate pouring temperature;
- keep transfer and holding times in the ladle as short as possible;
- use clean ladles;
- pig residual metal prior to ladle re-filling;
- skim any dross from the metal surface before pouring,

While many serious casting defects, including badly run castings and cold shut and lap defects, are caused by low pouring temperatures, pouring excessively hot metal can lead to internal unsoundness, dimensional inaccuracy, core distortion and poor surface finish.

Metal tapped at a sufficiently high temperature to enable pouring at the correct temperature in a remote part of a foundry may be too hot for immediate use on a pouring line adjacent to the furnace. Accurate monitoring of metal temperature, preferably just before pouring, is essential and an immersion pyrometer is recommended for this purpose.

Checklist

- Avoid unnecessary superheating of the metal prior to any further processing and distribution.
- Ensure that the metal temperature in the melting furnace is high enough to compensate for temperature losses experienced during transfer and distribution to the moulding line.
- Employ correctly sized launders and ladle systems and fit insulated covers to minimise heat losses by radiation.
- Avoid unnecessary ladle transfers.
- Wherever possible, add alloying materials to the melting furnaces, rather than in the distribution network.
- Receivers used to even out fluctuations in metal demand should be heated, where possible.

4. MOLTEN IRON TRANSPORT SYSTEMS

4.1 Overview

Planning efficient metal transport systems from either prime melting or holding furnaces to the pouring station is an essential part of economic foundry operation. The design of such systems will have a significant effect on energy consumption, casting yield, scrap rate, labour requirement and general casting quality.

4.2 Technical Parameters

When planning molten metal distribution in the foundry, the following factors are important:

- required rate of metal transfer;
- ladle capacity and mode of transport;
- minimising manual effort;
- effective ladle return system;
- efficient launder/ladle pre-heating;
- provision for deslagging;
- pigging (pourdown) facilities;
- safety considerations.

The requirements of the distribution system can only be determined by a critical study of each individual plant, taking into account all process variables, together with any specified volume and metallurgical factors.

4.3 Distribution Systems

Primary distribution systems can be categorised as follows:

- bulk transfer of molten metal from holding furnaces for the purpose of replenishing other holding furnaces or pouring machines near or at the pouring station;
- large single batch transfer for pouring individual large castings: batches may be sub-divided into smaller ladles if lifting/transport capacity is limited;
- single batch transfer for sub-division into multiple pouring ladles near to the pouring lines;
- collection of metal in individual pouring ladles for direct transfer to the pouring station or line.

4.3.1 *Bulk Metal Transfer*

Bulk transfer of metal is common in large foundries producing a generic product such as spun pipe, or where several moulding lines are installed, as in a large automobile casting plant. By providing holding facilities to ensure a supply of metal at each plant, it is possible to improve the energy efficiency of a foundry. This is achieved by employing a central melting unit, which can be operated under optimum conditions, thus transferring molten metal in substantial batches. In general, the larger the batch of metal to be transported, the lower will be the specific energy loss incurred (see Section 2.3). The bulk transfer of molten iron is normally limited to foundries using a single base iron specification.

Where large batches of metal require transferring, overhead travelling cranes are recommended, particularly in jobbing foundries when pouring directly into the mould. This may not be practicable in modern automated plants, where a large proportion of the shop floor area may be occupied by production equipment that may impede the passage of suspended loads on cranes.

Mobile trucks and lift trucks can be used provided sufficient space is available for manoeuvring and safe routes can be established. It is also essential that all floor surfaces are maintained in good condition. Carriage systems and ladles must be specially designed and drivers must be protected from radiated heat and metal splashes.

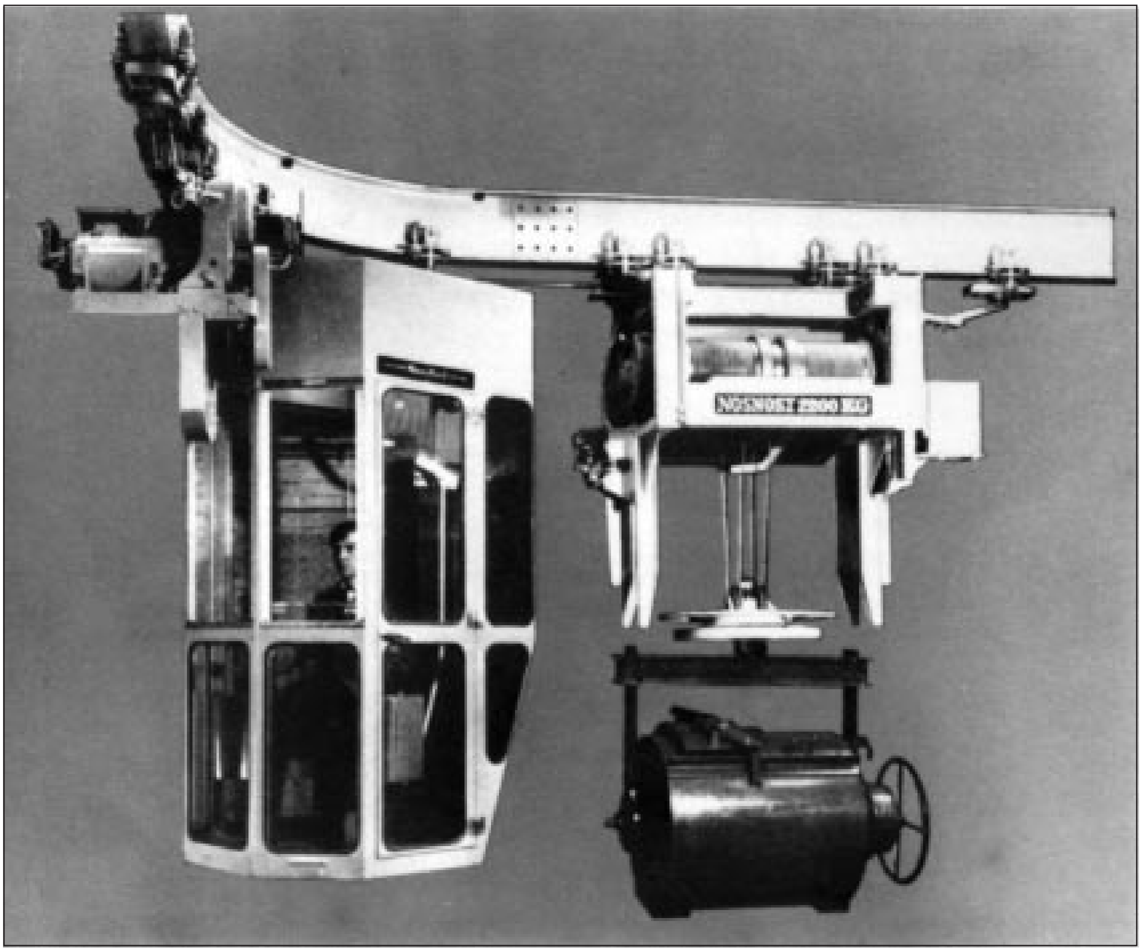

Fig 10 Large overhead monorail system

Where site conditions do not allow overhead cranes to be used to distribute molten metal, the choice lies between mobile truck systems, or overhead monorails such as shown in Fig 10.

Monorail systems are expensive and are practicable only where they can be installed as an initial part of the plant complex. This will enable runway systems to be designed and integrated with other structures. Generally, mobile truck systems will be the preferred option.

4.3.2 *Ladle Transfer*

In many foundries, it is impracticable to collect metal from the primary melting or holding furnace in the casting ladles, and uneconomical to provide a means of holding at the pouring station. In these foundries, it is normal practice to transport the metal in a large transfer ladle and to dispense the molten metal at the pouring line into smaller ladles, or a pouring machine, for casting. Transfer ladles can be transported suspended from overhead monorails, cranes or lift trucks, while casting ladles can be carried on monorails or light crane systems.

In the past, little was done to conserve energy, except where metal temperature losses were concerned. However, energy management is now recognised as a critical priority for both economic and environmental reasons. In most foundries, a careful examination of the molten metal distribution systems will reveal opportunities for energy and labour savings and for a reduction of wasted metal and scrap castings.

Checklist

- Efficient metal handling and distribution systems do not evolve; they are carefully planned and designed.
- The effectiveness of such systems will depend on a range of technical considerations.
- Energy efficiency is largely controlled by the bulk of iron to be transported, the distance involved, any subsequent treatments and the number of ladle transfers taking place.
- All handling systems must take into account the manner in which the moulds are presented for pouring.
- Metal transfer by overhead travelling crane is particularly applicable in jobbing foundries.
- Mobile trucks and monorail systems are frequently employed in modern automated plant where there are height restrictions.

5. POURING MOLTEN IRON

5.1 The Pouring Station

Moulds produced mechanically, in either batch quantities or by repetition type moulding systems, can be presented for pouring in a number of ways:

- *Static groups:* moulds are assembled and stored before pouring on gravity-roller conveyors or pallet systems.
- *Continuous:* moulds are carried past the pouring station on a continuously moving conveyor system or using a powered pallet conveyor or carousel unit (Fig 11).
- *Indexing (sequential):* moulds are indexed according to the moulding plant cycle and must be poured in the order in which they are produced. This method includes vertical joint flaskless moulding machines, such as the Disamatic.
- *Indexing (non-sequential):* moulds are systematically indexed according to the moulding plant cycle, but it is not necessary to pour the moulds in the same order in which they are produced. The moulds must be poured in the time allowed by the moulding cycle, as on indexing pallet-type mould conveyors.

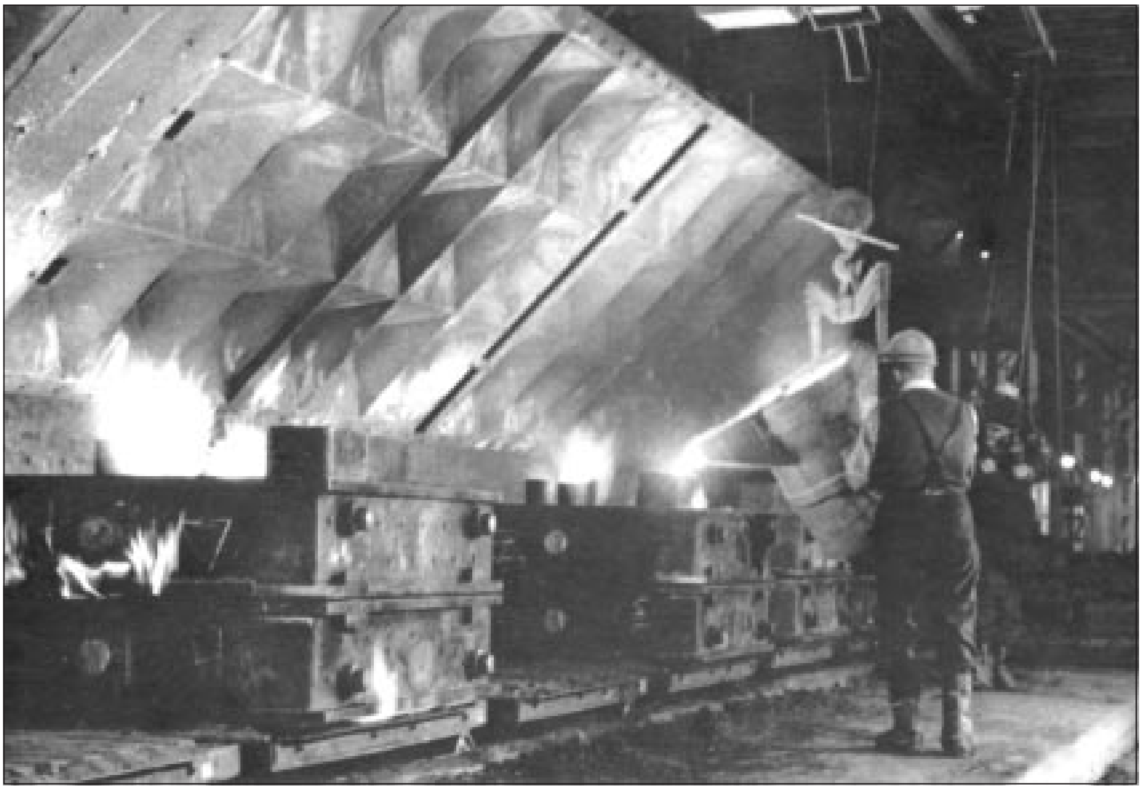

Fig 11 Pouring on a continuous moulding line

The maximum mould output will influence the choice of pouring method because it establishes the number of finite tasks to be performed and, to some extent, the speed of the moulding line. Modern moulding systems are capable of cycle times equivalent to 600 moulds per hour.

5.2 Automatic Pouring

During recent years, a range of automatic pouring machines has been developed for use in iron foundries. These are now widely used for dispensing both grey and ductile iron directly into the mould.

Using automatic pouring equipment generally results in energy savings due to:

- reduced transfer losses and improved casting yield;
- greater utilisation of the primary melting capability;
- improved plant utilisation.

Automatic pouring removes operators from a potentially hazardous environment and can reduce labour requirements.

The technique enables accurate predetermined quantities of molten metal to be dispensed in accordance with mould requirements. In addition, it eliminates the need for extended pouring zones and transfer systems, while providing the capacity to pour moulds consecutively within the cycle time of the moulding system, thus achieving high output rates.

Automatic pouring equipment maintains a reservoir of molten metal and ensures that it is available at all times to match mould line requirements, while optimising melting furnace and molten metal transport procedures. Molten metal can be held at the correct pouring temperature during plant stoppages and work breaks by applying induction-heating systems to the pouring unit. This usefully reduces 'melting plant' losses by eliminating the production of unusable metal.

5.3 Types of Automatic Pouring Machines

Pouring machines have been developed to suit the requirements of automatic moulding systems. The use of automatic pouring machines generally results in significant overall energy savings due to reduced transfer losses and improved casting yield, combined with more efficient use of the primary melting capability and improved plant utilisation.

The two main types of automatic pouring machines are discussed below.

5.3.1 *Bridge-Type Bottom Pouring Vessels*

These are based on a refractory lined vessel fitted with a stopper rod/nozzle system for pouring. The unit is mounted on a bridge structure above the mould string, generally on a carriage adjustable on its XY axes. This enables the unit to be accurately positioned above the pouring cup, and is shown in Fig 12. The stopper opening and pouring profile can be controlled automatically, and may be programmed to individual casting requirements or to use laser/optical detectors.

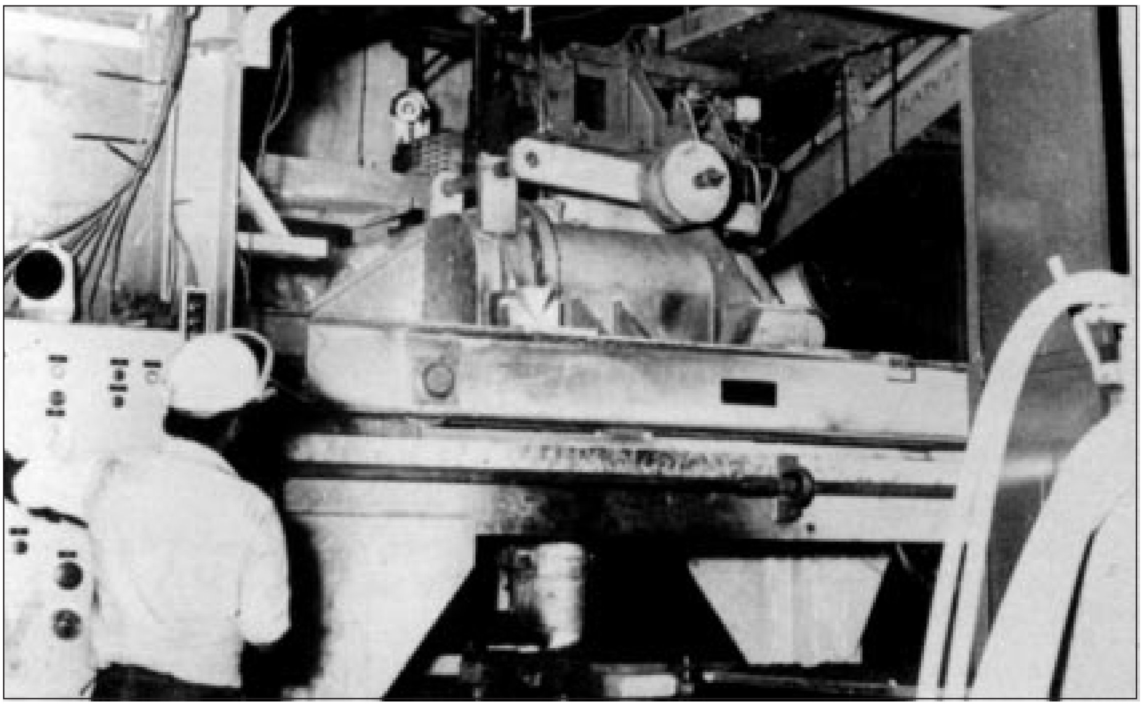

Fig 12 Bottom pouring stopper-rod unit

When employed on high output moulding machines, this type of pouring unit is used without any auxiliary heating. It relies on a high throughput of molten metal and a well-insulated lining to restrict temperature losses to acceptable levels. More commonly, channel type inductors are fitted to provide a means of maintaining molten metal temperature in the vessel.

The bridge-type bottom pouring vessel is the most widely used method of automatic pouring. It is generally constructed as a sealed vertical channel induction heated furnace, although some coreless systems have been developed. The unit is internally pressurised with air, or occasionally nitrogen, and has a teapot type inlet and pouring spouts. Under normal operating conditions, the level of metal in the vessel is pressure-controlled so that a fixed level is maintained in the pouring spout. Automatic compensation is effected by a control system, which responds to signals from contact probes in the pouring spout during dispensing and while metal is added to the vessel via the filling spout.

5.3.2 *Conventional Stopper Rod Systems*

Most modern units incorporate a nozzle/stopper rod system in the pouring spout to dispense metal accurately into the mould. Very accurate shot weights can be achieved by this means and the system can cope with fast modern moulding lines. In most cases, the stopper opening and closing sequence is controlled by an adjustable timer. Computer-controlled systems can be pre-programmed and integrated with the moulding plant to automatically recognise changes in casting parameters.

In cases where pressurised gating systems are employed, it is necessary to provide a facility for profiled pouring. This enables the flow rate from the pouring machine to be varied to suit the filling characteristics of the mould. 'Tech-mode' systems enable selected pouring data to be defined and filed in the computerised control unit. Another effective method is to control the metal level in the sprue cup during pouring. The most successful system developed so far is based on the use of a laser sensing device. This provides reactive control of the stopper rod mechanism through a processing unit and is shown in Fig 13.

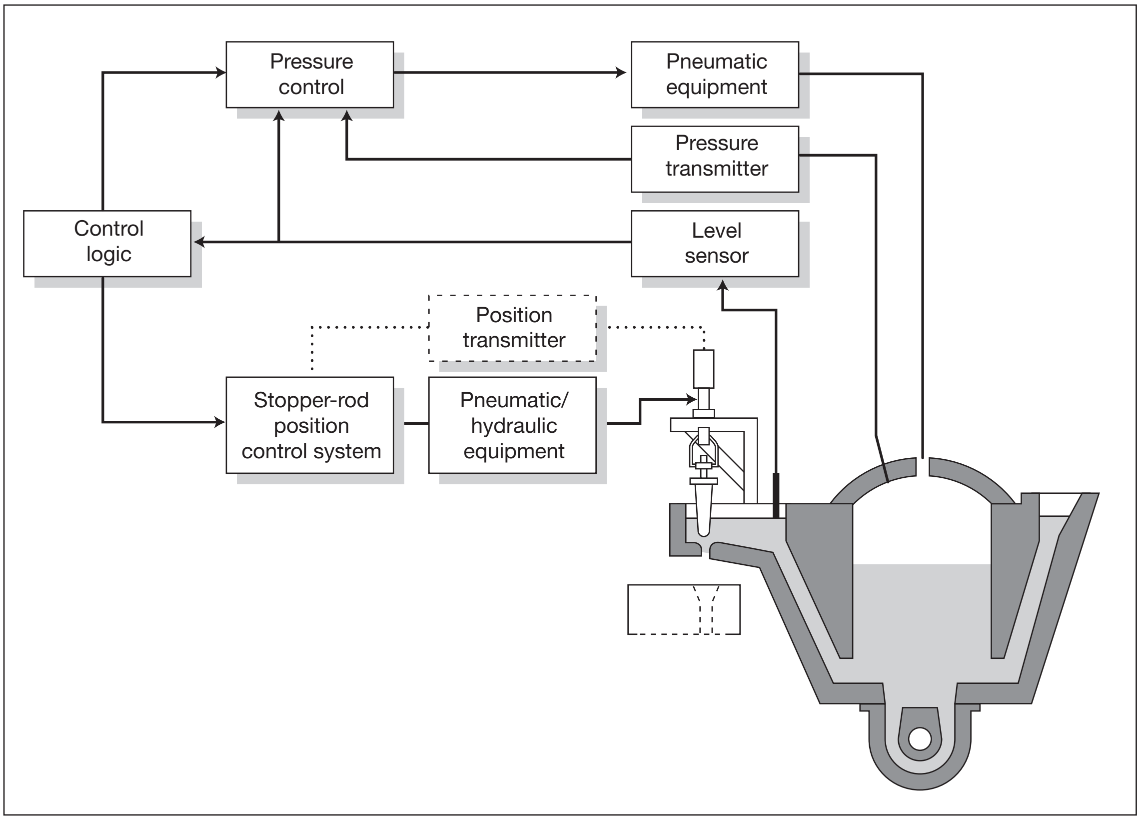

Fig 13 Pressure-pouring vessel with stopper-rod control (courtesy of ASEA)

Following careful development of pressure systems and the construction of pouring units, it is now feasible to use automatic pouring machines for dispensing magnesium treated metal for the manufacture of ductile castings.

Checklist

- The use of automatic pouring equipment can result in significant energy savings and improved casting yields.
- Foundries contemplating installing automatic pouring should give consideration to the two main types: bridge-type bottom pouring vessels and conventional stopper rod systems.
- Induction heating systems help maintain the correct temperature and reduce melting-plant losses.

6. SAFETY CONSIDERATIONS

Handling and pouring molten metal is potentially dangerous, and it is necessary to minimise the risk to operators and all other foundry personnel at all times. Basic precautions include:

- Implementing proper furnace tapping procedures, including care of launders, spouts and other equipment;
- Using appropriate Personal Protective Equipment (PPE) for operators;
- Establishing good maintenance systems for ladles, including proper preheating systems;
- Ensuring the correct maintenance of lifting and transportation equipment;
- Implementing good housekeeping practices in all areas;
- Using sound moulds, properly weighted and clamped;
- Installing adequate systems for fume capture and general ventilation;
- Maintaining proper facilities for pigging excess metal and removing dross from ladles;
- Fitting flush grid floors over shallow pits in all pedestrian areas subject to the spillage of molten iron;
- Keeping concrete floors and spillage pits dry.

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